A STUDY OF THE TIME EFFECTS OF DISTANCE, DIRECTION, AND SIMULTANEITY ON MANUAL TRANSPORT MOTIONS

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

ABSTRACT

The speed with which synthetic motion and time study will make the transition from art to science is dependent on the speed with which its method of application will be simplified and its tabulated time values will be refined. This research was intended to fulfill three specific needs for the refinement of synthetic motion and time study. First, an experimental procedure which can be duplicated by others has been developed. Second, through use of this experimental procedure, the estimated normal movement times for fundamental transport empty motions, of varying distances, made while seated were established. Third, the comparative time effects of different body members making like movements of like distances were measured.

All of the experiments were made at a standardized work place. The motions were timed by means of the Auto-Graphic Time Study Machine developed by Doctor W. Dale Jones. This machine is capable of automatically timing movement times to the nearest interpolated 0.0001 minute. Three male and three female subjects were selected for the experiments.

All of the experiments performed involved a common basic motion pattern consisting of two phases. First, a basic task or "key" task is performed. Immediately following this a task entailing the movements for which the time is required, the "tested task," is performed. Each key task and accompanying tested task was individually timed with the Auto-Graphic Time Study Machine. Performance of the key task provides

a means of applying a speed rating factor to the tested task times for the purpose of normalizing them.

Six tests were conducted, one for each of the six experimental subjects. Each test consisted of the following twenty-four experiments:

Push-Pull movement

One hand only, distances of 3", 6", 9", 18", 24", and 30".

Both Hands, distances of 3", 6", 9", 18", 24", and 30".

Lateral movement

One hand only, distances of 3", 6", 9", 18", 24", and 30".

Both hands, distances of 3", 6", 9", 18", 24", and 30".

Each experiment consisted of five performances of the key task and accompanying tested task. All of the experiments were performed at a very fast speed so that variation could be reduced.

Percentage difference in the normal time of twelve-inch motions, the key task, compared with longer motions are shown by means of curves. These percentages are based on assumed normal times for the key tasks, and when satisfactory normal times have been agreed upon (a basis for further research) for these key tasks, the percentages taken from the curves may be used to arrive at normalized movement times for the various distances.

The results of the final phase of the research indicate:

(1) Approximately six per cent more time is needed to perform the two-hand lateral movements than was needed to perform the one-hand lateral movements.

(2) There is no significant difference in normal times for performing the one-hand push-pull movements and the two-hand push-pull movements.

(3) Approximately twelve per cent more time is required to perform the one-hand push-pull movements than is required to perform the one-hand lateral movements.

(4) Approximately six per cent more time is required to perform the two-hand push-pull movements than is required to perform the two-hand lateral movements.

CHAPTER I

INTRODUCTION

Synthetic Motion and Time Study.--Synthetic motion and time study, as referred to in this thesis, is a procedure whereby manual operation methods and their respective normal times are derived through the use of tabulated time values for single movements or small combinations of movements. For the purpose of brevity, synthetic motion and time study will hereafter be referred to as "synthesis."

A properly developed and skillfully applied synthesis system can yield time standards which are more refined and more consistent than stop watch studied time standards. Synthesis can also aid materially in developing more refined methods. It is of greater advantage in operator training and provides better employee relations than stop watch motion and time study.

Criticism of Present Systems.--Critics of synthesis systems mention several seemingly meaningful objections to them. A common objection is that there is no way to determine whether the data are based on valid experimental methods since the methods are not written into the literature except in a vague general way. Thus, there is reason to suspect that they may not be based on valid scientific methods.

There are several synthesis systems presently being used in industry. However, various investigations of these systems indicate that normal times established by each of the systems vary significantly for the same type of motion. This would infer that no more than one of these systems can be correct.

Another common objection to synthesis systems is the difficulty of their applications. A high degree of skill, acquired only after much training and actual practice, is needed before a time study engineer can synthesize jobs.

Still another objection that critics have frequently mentioned is that synthesis systems apparently were developed in the belief that basic movement times are additive and do not depend on preceding and succeeding movements. Several researches reveal this assumption to be invalid. In order to determine the normal movement time for one movement, the nature of the preceding movement and the following movement should be considered.

Another common criticism of synthesis systems is that they apparently fail to recognize differences in motion times due to differences in body members used to move any given distance. This shortcoming is evidenced by the fact that they fail to recognize differences in the direction of arm motions as influencing the time for those motions. Several investigations reveal that direction does affect the motion times since there will be different parts of the arm in use for motions of different direction for a given distance.

Need for Refinement.--The foregoing shortcomings are of sufficient significance to have markedly impeded the general usage of synthesis. Synthesis today is seemingly too much an art and too little a science. The speed with which it will make the transition from art to science is dependent mainly on the speed with which it will be simplified and refined.

Specifically, there appear to be four fundamental requirements for accomplishing these requirements of simplicity and refinement. First, synthesis must be more accurate. Second, the methods employed in deriving synthesis values must be demonstrable and verifiable. Third, synthesis must be more complete, giving recognition to comparative time effects of movements of like distances made with unlike body members, and the time effects of simultaneity. Fourth, the data must be tabulated clearly so that an engineer with a minimum of knowledge of synthesis can use them to develop accurate, consistent work standards.

CHAPTER II

LITERATURE SURVEY

History of Synthetic Motion and Time Study.--Frederick W. Taylor, the originator of systematic stop watch study, should be credited with the first published recognition of the need for synthesis. While working as a time study analyst at the Midvale Steel Company in 1881, he conceived the following to be the constructive work of time study:

h. Add together into various groups such combinations of elementary movements as are frequently used in the same sequence in the trade, and record and index these groups so that they can be readily found.

i. From these several records, it is comparatively easy to select the proper series of motions which should be used by a workman in making any particular article and, by summing the times of these movements and adding proper percentage allowances, to find the proper time for doing almost any class of work.

j. The analysis of a piece of work into its elements almost always reveals the fact that many of the conditions surrounding and accompanying the work are defective; for instance, that improper tools are used, that the machines used in connection with it need perfecting, and that the sanitary conditions are bad, etc. And knowledge so obtained leads frequently to constructive work of a high order, to the standardization of tools and conditions, to the invention of superior methods and machines. (1)

In his book, Shop Management, Taylor predicted that eventually a sufficient body of work time standards would be accumulated and put into a single handbook to make further stop watch time studies virtually unnecessary except in unusual operations. (2)

With Taylor's help, Sanford Thompson developed standard time data for the building trades shortly before 1900. Dwight Merrick developed these data for manufacturing processes, and shortly after 1900 he applied them to molding operations at Watertown Arsenal and to work on Gisholt Boring Mills at Winchester Repeating Arms Company.

These first efforts to formulate the synthesis called for by Taylor met with significant obstacles. First, with the stop watch as a timing instrument, it was necessary to time work in much larger divisions than the required individual movements or small combinations of movements. This was due to the human and mechanical error inherent in stop watch timing and the inability of the time study observer to accurately rate performances stop watch timed in small divisions. Secondly, because the time studied work divisions entailed great numbers of movements, their utility was restricted to the specific type of work composed of these work divisions. The elemental times were certainly not the elementary movement times envisioned by Taylor.

Recognizing the need for refined timing and analysis of individual movements, Frank B. Gilbreth, shortly after 1900, conceived the micromotion study technique. Barnes describes this technique as, ". . . the study of the fundamental elements or subdivisions of an operation by means of a motion-picture camera and a timing device which accurately indicates the time intervals on the motion-picture film." (3) However, this technique was still unsatisfactory for the acquisition of movement times since the inaccuracy entailed in timing photographed movements to the nearest film frame was often a large percentage of the movement time itself. This disadvantage could be overcome by projecting film at high speeds, but the cost of film and film analysis would be very high.

Because of the limitations of stop watch time study and micromotion study, little progress was made toward the development of the synthesis called for by Taylor until nearly 1930, when Asa B. Segur developed a system that measured basic motions and sensory reactions. As a basis for his system he evolved the Segur Law, which states, "Within practical limits the times required to perform true fundamental motions are constant." (4) This law would be very useful if he had submitted evidence of its validity and if he had stated what was meant by "practical limits." Segur's synthesis system is called Motion-Time-Analysis. Although it has been extensively used, it is kept a secret and must be installed by the A. B. Segur Company. This first commercial synthesis system is very refined and requires a great amount of training to apply. This is borne out by Segur's statement, "The art of description is perhaps the most important in Motion-Time Analysis. Most difficulties in the application of Motion-Time-Analysis can be traced to poor descriptions." (5)

Because of the difficulty of this refined, intricate synthesis system, special purpose systems were developed. The first of these was developed by the General Electric Company in 1934 and 1935. It is described by Barnes in his text book, Motion and Time Study, and is applicable only to certain types of assembly operations. (6) Moreover, it treats combinations of movements rather than individual movements. It appears to be the first published system for the industrial engineering profession to analyze and improve upon.

The Western Electric Company developed a similar system, which has been recently published. Like the General Electric system, it is limited to assembly operations of "get" and "place" motions. (7)

In 1938 Walter G. Holmes published a synthesis system called Body Member Movement Times which includes standard time values for body member movements and nerve reactions. (8) Like Segur's system, this synthesis system was designed for general use on all types of manual operations. It was used at the Timken Roller Bearing Company but, as far as can be determined, has seen little other use. It was probably the first universal system to be published for general use.

Recognizing the complexity of the highly refined Segur and Holmes systems, and their consequent limited usage, a group of engineers at the Radio Corporation of America developed a system called the Work Factor system. This synthesis method was described in 1945 in Factory Management and Maintenance. (9) This system represents an effort to establish a synthesis method that is easier to apply than that developed by Segur. It, like Segur's system, is a universal or general use system which can be applied to many types of operations. It has been used quite extensively in recent years, principally for highly repetitive bench assembly jobs.

Maynard, Stegemerton, and Schwab developed a system called Methods-Time Measurement (MTM), which they described in a text book published in 1948. (10) The synthesis application description entailed in this book is more detailed than that of the other synthesis systems which are available to the public. Moreover, this book briefly describes methods used in collecting and analyzing the data upon which the tabulated synthesis time values are based. The Methods-Time Measurement synthesis system is not as refined as the Segur and Work Factor synthesis systems in that it treats combinations of movements rather than individual movements. This does simplify the application of synthesis, but in so doing seemingly sacrifices precision in estimating total normal times for jobs.

In 1951 J. D. Woods and Gordon, Limited, published a system called Basic Motion Timestudy. (11) This system, like Methods-Time Measurement, is not as refined as the previous synthesis systems in that it treats combinations of movements rather than individual movements. The method of application of this system has also been described in the literature available to the public, but not as thoroughly as that of Methods-Time Measurement. The principal advantage of this system is that it has defined the motions considered more precisely than other systems. This means that it is easier to learn and to apply and that there might be less chance for error in application.

These recently developed synthesis systems indicate a trend toward more ease of application and less involvement of judgment. However, they also indicate a trend toward the treatment of movement combinations rather than individual movements with the possible loss of some accuracy.

Advantages of Synthesis.--Synthesis is reported by its users to be advantageous over stop watch motion and time study (hereafter called "stop watch study" for brevity) in several respects. The more important of the many reported advantages will now be briefly discussed.

The synthesist can develop refined methods and time standards in advance of production because the time for doing a job depends on the motions used. Since synthesis involves tabulation of time values corresponding to each motion, the sequence of motions resulting in the lowest time value may be developed by merely determining which motions are needed to do the job using each of the possible methods. Because of the emphasis on relating time directly to motions, the synthesis systems are also very useful for improving existing methods as well. These attributes of synthesis make it possible to accurately estimate labor costs and to refine work scheduling on both individual and production line operations. The feeling of the developers and users of synthesis toward these characteristics of the systems is typified by the following statement of Maynard, Stegemerten, and Schwab, "The method determines the time, and the time establishes which is the best method. It is felt that the Methods-Time Measurement procedure . . . which considers methods and time simultaneously solves the difficulty in cases where it is applicable." (12)

The synthesis systems are an aid in developing time formulae and tables for standard elemental time data. One writer claims that in many instances the time formulae may be developed in twenty-five per cent less time than would be required when using stop watch study. (13) Moreover, this stop watch derived standard data may not be used generally among several plants as can synthesized standard data, because the elemental time values are comprised of many motions, the separate times for which are unknown. Thus, unless the jobs accommodated by the standard data are performed in virtually the same way in the various plants, the data would be invalid.

Synthesized time standards, when established in a refined manner, are generally more consistent than stop watch derived time standards. The reasons for this advantage are two-fold. First, rating judgment is replaced by an easier type of judgment - synthesis selection (selection of correct motions). Secondly, each job is divided into more component parts, giving greater chance for plus and minus errors in the normal work time estimates to cancel.

Some writers have seemingly exaggerated the claim of consistency of synthesis in saying that synthesized time standards are more accurate than even the most refined stop watch study standards. Segur, for instance, says his system sets time standards "minutely and exactly." (14) However, since the original ratings entailed in development of the synthetic normal movement times were judgments, such claims might well be invalid.

Synthesis facilitates operator training in that it enforces a detailed written description of the synthesized refined job method. One company, for instance, claims as much as fifty per cent reduction in job training time needed for new employees since adoption of synthesis methods. (15)

Synthesis, if properly handled, may result in fewer rate grievances than stop watch study. The reasons for this advantage are three-fold. First, the greater consistency of incentive standards is conducive to employee satisfaction with the standards. Secondly, synthesis overcomes the traditional obstacle of bad feeling caused by the stop watch, which was once used in a very arbitrary, unscientific manner. Finally, the consistency of synthesized standards may be easily demonstrated to workers; that is, it can be shown that like times are always allowed for like movements when synthesizing time standards.

Many companies have reported in the literature that they have completely abolished the stop watch. However, it is probable such statements are exaggerations, because many skilled motions cannot be adequately synthesized by present synthesis systems.

Shortcomings of the Present Systems.--One of the principal objections to synthesis in the past has been the secrecy that has been maintained pertaining to methods of acquiring and evaluating the time data. A. B. Segur, in commenting on this states that he does not allow any part of his system to be published for general application because he feels it might be misused. Most critics feel that this is not a valid reason for secrecy. It would seem that better professional practice would dictate the publication of the system for evaluation and possible improvement by the industrial engineering profession. In view of this, two systems that have been published recently (Methods-Time Measurement and Basic Motion Timestudy) have tried to avoid such criticism by publishing their experimental methods.

The present synthesis systems are not valid for use in establishing sufficiently accurate time standards for work requiring high skill. Moreover, no allowances are provided for fumbles inherent in certain types of work.

The refined synthesis systems seem to be avoidably complicated in their method of motion description. Consequently, more training skill is needed to apply synthesis than is required of stop watch study. On the other hand, the simplified systems, in an effort to obtain single, wallet-size synthesis tables, appear to be simplified at a significant expense of accuracy. For example, the two by three inch Methods-Time Measurement table recognizes only six types of reach motions, and the Basic Motion Timestudy table considers but five.

The various synthesis systems do not seem to adequately deal with the time effects of various motion impedances. Even the refined Work Factor system considers as being equal the time effects of necessity of exerting care during movement, necessity of stopping in movement, the influence of weight being handled, etc. (16) Many of the systems do not differentiate between motions to the front (push-pull), side (lateral), seated and standing, etc. Davison says, "Neither Holmes nor Work Factor considers the effect of simultaneous movements on performance time, although quite a number of experimental investigations show a significant effect." (17) Methods-Time Measurement assumes, by the "Principal of the Limiting Motion," that there is no slow down of one motion when another motion is performed simultaneously.

Davidson compared the Work Factor, Holmes, and Methods-Time Measurement systems and claimed that the motion-times differed significantly. He therefore reasoned that only one of these systems could possibly be accurate and probably none were. (18) This does not mean that the synthesis systems should not be used. In actual practice most of these differences would be both plus and minus and would tend to cancel. Therefore, total time standards set by each of them would not, in most cases, be different in as great a proportion as differences of individual movement times.

Many psychologists and others object to synthesis as being contrary to the Gestault theory of psychology. In stating this objection, Ghiselli and Brown write, "Any task must be thought of as an integrated whole whose characteristics are changed by any of its parts." (19) This says, in effect, a task is more than the sum of its atomized parts, but also includes the interactions between those parts. Nadler and Wilkes conducted experimental investigations of these interrelationships. Their findings indicate that a change in one therblig can significantly affect the time of the next performed therblig. (20)

Basic Motion Timestudy appears to be the first synthesis system to consider these interrelationships between therbligs. In recognition of this, time values are tabulated for different types of reach motions, according to the therblig following the motion. Normal time values for motions made up of reach and grasp therbligs are also tabulated, indicating that the time for a grasp therblig depends on the length of the reach therblig preceding it. An accurate system should investigate all possible interactions between therbligs. This apparently has not been done by the developers of the present systems.

Another shortcoming of the present synthesis systems is concerned with the methods used to rate the speed entailed in the actual observed motion-times upon which the synthesis tables are based. According to the literature, rating was generally accomplished by applying subjective rating factors to individual observed times or groups of observed times. Also, the opinions of but few people were averaged in order to procure these rating factors. Thus, it would seem that the synthesis systems have incorporated one of the weaknesses of stop watch study. It would have been more accurate to have averaged the opinions of a large number of trained people in arriving at rating factors used to normalize the measured movement times.

<u>Validity of Synthesis</u>.--As far as can be discerned from a search of the literature, there are no published results concerning tests of validity for Segur's system, Holmes' system, the Work Factor system, or Basic Motion Timestudy. The developers of the Methods-Time Measurement system have included one test of its validity in their book. This entailed a comparison of the standard times determined for twenty-seven jobs by stop watch study and by Methods-Time Measurement. However, it does not appear to have been a very objective test. Moreover, questionable conclusions were made because, first, the comparison entailed two unvalidated methods and, second, no recognition was given to possible variation between the individual standards. The algebraic sum of the differences in normal times were used in comparing all the jobs. (21)

Davidson made an investigation at Ohio State University, as cited previously, in which he concluded that the Work Factor, Holmes', and Methods-Time Measurement system differ significantly as to their motion-times. In addition there is some mention in the literature of tests of the validity of Methods-Time Measurement made at Pennsylvania State College. The results of this investigation indicated that the published time values for transport loaded motions do not make adequate allowance for the influence of weight. (22)

In developing their motion-time data, the developers of Motion-Time-Analysis, Work Factor, and Basic Motion Timestudy used controlled laboratory studies of individual motions or small groups of motions. The Methods-Time Measurement system is based on micromotion analyses of film made of actual production jobs. This writer feels that the first method of analysis is superior since it is the best available method to separately study the effect of each variable factor that may influence the normal time needed to do a job. In answer to criticism that laboratory findings cannot be extended to industrial conditions, the J. D. Woods and Gordon Company writes very appropriately, "If a time value for a given motion pattern was to be transferable from one setting to another in dealing with plant work, it seemed reasonable to require that it should be equally transferable to the laboratory setting." (23)

Conclusion.--Like any other form of measurement, accuracy of synthesized motion and time standards is dependent on the accuracy of the tool (the tabulated motion times) and the accuracy with which the tool is used. It does appear reasonable to say that synthesis, when skillfully applied, can yield time standards which are more refined and more consistent than stop watch studied time standards. Also, it appears reasonable to say that synthesis can aid materially in providing more refined methods analysis, can facilitate operator training, and can provide better employee relations than those attendant to stop watch study.

In order to fully utilize these advantages of synthesis, the synthesis itself needs to be simplified and refined. Specifically, there appear to be four fundamental requirements for accomplishing these requirements of simplicity and refinement. First, synthesis must be accurate. Second, the methods employed in deriving synthesis values must be demonstrable and verifiable. Third, synthesis must be more complete, giving recognition to comparative time effects of movements of like distances made with unlike body members, the time effects of simultaneity, and the interactions of therbligs. Finally, the data must be tabulated clearly in order that engineers with a minimum knowledge of synthesis can use it to develop accurate, consistent time standards.

CHAPTER III

OBJECTIVE

This research was intended to fulfill three specific needs for the refinement of synthesis. First, application of the experimental method which can be duplicated by others has been developed in behalf of the research test to be described. This application of the experimental method is recommended for all researches intended for refinement of synthesis. Second, through use of this experimental procedure, the estimated normal movement times for fundamental transport empty motions, of various distances, made while seated, were established. Third, through use of this experimental procedure, the comparative time effects of different body members making like movements of like distances were measured. This phase of the research was intended to yield per cent slow down inherent in non-fundamental motions in comparison with the above-mentioned fundamental motions.

In summary, the following are the objectives of this thesis:

(1) To develop a universally acceptable application of the experimental method to be used for the development of synthetic motion times.

(2) To determine the percentage difference in the normal time of twelve-inch motions compared with longer motions.

(3) To test the following hypotheses:

(a) That two-hand lateral motions are significantly slower than one-hand lateral motions when both motions are performed at maximum speed.

(b) That two-hand push-pull (upper arm) motions are significantly slower than one-hand push-pull motions when both motions are performed at maximum speed.

(c) That one-hand push-pull motions are significantly slower than one-hand lateral motions when both motions are performed at maximum speed.

(d) That two-hand push-pull motions are significantly slower than two-hand lateral motions when both motions are performed at maximum speed.

(4) To establish the degrees of slow-down represented in comparisons (3a), (3b), (3c), and (3d), in cases of significant difference.

CHAPTER IV

EXPERIMENT FACILITIES

Work Place.--The work place was made to conform to the standards suggested by Doctor Ralph M. Barnes. (24) An adjustable chair was provided so that the hand of each subject could be located from one to three inches lower than the elbow. A foot rest was provided that could be adjusted to the individual needs of each subject. The work table was kept free of anything that might distract the subject.

Timing Device.--The motions were timed by means of the Auto-Graphic Time Study Machine developed by Doctor W. Dale Jones and shown in Figure 3. This machine is capable of timing automatically, on separate charts, movement times as small as 0.003 minute to the nearest interpolated 0.0001 minute. It is described by its designer as consisting of five basic components:

1. A synchronous motor which revolves a cylinder at either four or forty revolutions per minute as long as the machine is in operation.

2. Six mutual, chart-bearing shells which slip-fit about the cylinder.

3. A recording mechanism, consisting of six relay-actuated posting devices.

4. An indexing mechanism, consisting of a mount upon which the posting devices are attached, which is moved horizontally by means of a rack and pinion either manually by turning a knob or automatically by means of a relay controlled pawl and ratchet.

5. Six relay-controlled stops which regulate the starting and stopping of the six chart-bearing shells. (25)

The recording mechanism may be controlled either manually or automatically. During this investigation it was controlled automatically by means of several microswitches set up on the work table.

This time study machine was tested with a synchronous, electrically actuated interval timer operated simultaneously with the machine. The error inherent in this timer is probably less than 0.005 second or 0.00008 minute. Twenty-five readings were made, and it was found that the average error of the first cylinder of the Auto-Graphic Time Study Machine was -0.00002 minute. These errors showed a standard deviation of 0.00010 minute. Dividing this standard deviation by the square root of the sample size, a standard deviation of the sampling distribution of errors is obtained of 0.00002 minute. Since the time values were to be read to the nearest 0.0001 minute, it was felt that this error was negligible.

The twenty-five tests of the second cylinder showed an average error of -0.00024 minute with a standard deviation of 0.00022 minute. Dividing this standard deviation by the square root of the sample size results in a standard deviation for the sampling distribution of errors of 0.00004 minute. On the basis of this test, the data procured from charts on the second cylinder were adjusted by a value of + 0.0002 minute.

The data procured in this test are tabulated in Table 6, and the calculations used are shown in Figure 4.

Experimental Subjects.--Three male and three female experimental subjects were selected so that any effect of sex on movement times would be minimized. None of the subjects was skilled in work of this type. However, it was felt that this was not objectionable because of the fundamental nature of the motions to be studied. The ages of the subjects varied from twenty-two to thirty. These ages seem to be within the normal age bracket for workers doing work of this type. The subjects were each tested with the Moore Eye-Hand Coordination Test, developed by Doctor Joseph E. Moore at the Georgia Institute of Technology, prior to each experiment. (26) The scores were all above the sixty percentile rank for college people. All of the subjects were right handed and all tests made of one hand motions were made using this hand. Data concerning the sex, age, occupation, Moore Eye-Hand Coordination Test score, and arm length of each subject is tabulated in Table 7.

CHAPTER V

EXPERIMENTAL PROCEDURE

All of the experiments performed involved a common basic motion pattern. This pattern consists of two phases. First, a basic task or "key" task is performed. Immediately following this, a task entailing the movements for which the time is desired is performed. Such tasks will hereafter be referred to as "tested tasks." Each key task and accompanying tested task were individually timed with the Auto-Graphic Time Study Machine. Performance of the key task provides a means of applying a speed rating factor to the tested task times for the purpose of normalizing them.

Orientation.--The subjects were first taught the key task consisting of a one-hand push-pull motion. In accomplishing this task, the subject moves his hand from a microswitch located three inches to the left of the first switch. Each experiment subject was instructed to perform the key task at a very fast speed, since previous investigations indicate there is less variation in time (inconsistency) in performing a motion at a very fast speed than at a slower speed. A metronome was used to aid the subjects in achieving and maintaining the desired speed.

Since the speed rating exhibited on any given key task was to be applied to the time of the accompanying tested task, consistent movement speed throughout the key task and accompanying tested task was required for valid results. Accordingly, the subjects were repeatedly cautioned during the experiments to strive to maintain the same amount of effort in performing the key task and the accompanying tested task. Also the subjects were asked to move at the rapid speed used during this initial practice period.

Work Pattern.--Six tests were conducted, one for each of the six experimental subjects. Each test consisted of the following twenty-four experiments:

Push-pull movement

One hand only, distances of 3", 6", 9", 18", 24", and 30".

Two hands, distances of 3", 6", 9", 18", 24", and 30".

Lateral movement

One hand only, distances of 3", 6", 9", 18", 24", and 30".

Two hands, distances of 3", 6", 9", 18", 24", and 30".

Each experiment consisted of five or more performances of the key task and accompanying tested task. The reason for sometimes securing more than five performance times is explained later in this thesis.

As indicated above, the first experiment performed during each test treated the one-hand push-pull motion. Referring to Figure 5, the experimental subject was instructed to start this experiment with the hand on the table in front of him. He then moved his hand to the highly sensitive microswitch on his right, lightly touched this switch (thereby beginning the timing of the key task), and immediately moved twelve inches to a white marker on the table. This marker is located on the subject's right in Figure 5. He returned twelve inches to the second (middle) microswitch, thereby completing the key task and beginning the tested task. The subject immediately moved his hand to the marker on the table that marked the distance being studied (the tested task distance) and then back to the third (left) microswitch, thereby completing the tested task. The subject then awaited instructions to proceed with the next performance. Experiments were made in this manner for tested one-hand push-pull tasks of three, six, nine, eighteen, twenty-four, and thirty inches.

The next experiment of each test entailed two-hand push-pull motions for the above-mentioned distances. The work pattern for these experiments was the same as for the one-hand push-pull motions except that the subjects moved both hands forward and back together. The subjects were cautioned against permitting one hand to support the other instead of exerting equal effort in each arm. Also, they were instructed to touch the markers and switches simultaneously with both hands.

The next experiments entailed the one-hand lateral motions (motions to the side of the body) involving the above-mentioned distances. For this series of experiments, the switches were turned so that they were in a line perpendicular to the front of the table in front of the subject. The first microswitch was located farthest from the subject, the second was in the middle, and the third was closest to the subject's body. The microswitches faced the experimental subject's right so that he could move his hand laterally to them. The subject was instructed to start each performance with his hand at his right on the table. He then moved through the key task and the tested task as before, moving the prescribed distances to markers located on the table to the right of the switches.

The last series of experiments entailed two-hand lateral motions. These motions were simultaneous, symmetrical motions in which the subject moved both hands to markers at their respective sides simultaneously and then back together. For these experiments the white markers were located on both sides of the microswitches. The subjects were instructed to activate the switches with the right hand and to touch the fingers of the left hand to those of the right hand at the same instant. They were further instructed not to turn their heads in both directions in making the long reaches, but rather to turn only to the right, if necessary. Experiments were made in the previously explained manner, for the previously tested distances.

In addition to these four series of experiments, each experimental subject performed three other experiments. These experiments were conducted for the purpose of obtaining estimated normal times for the lateral and the two-hand push-pull key tasks, as explained in the section "Analysis of Data." The first of these experiments consisted of the previously described one-hand push-pull key task and a tested task consisting of a twelve-inch two-hand push-pull motion. The second experiment was again composed of the previously described one-hand push-pull key task with a tested task consisting of a twelve-inch one-hand lateral motion. The third experiment consisted of this twelve-inch one-hand lateral key task and a tested task consisting of a twelve-inch two-hand lateral motion.

Motion Timing.--During each experiment, touching the first sensitive microswitch caused the first chart-bearing shell in the time study machine to start revolving. Actuating the second switch caused the electric relay-controlled poster within the time study machine to record a tiny indention on the now moving Time Chart No. 1. The second chart-bearing shell started revolving simultaneously with this posting to the first chart. Touching the third switch caused the poster to make a tiny indention on the now moving Time Chart No. 2. Since these time-chart-bearing shells started revolving at the same instant the key tasks or tested tasks started, and since the charts revolved during the activity at a constant, known speed, the distance between the end of the chart and the posting can be converted directly to time. These distances were measured and the time values tabulated for each performance for both the key task and the respective tested task.

The type of chart used during the tests is shown in Figure 6. Since there are fifty small divisions on each chart and since the cylinder revolves at four revolutions per minute, the distance between each of the small divisions represents 0.0008 minute. By means of interpolation, time values measured to the nearest 0.0001 minute were estimated. The time values for the first five consistent performances (five key task times together with their respective tested task times) for each experiment were tabulated. Any performance that included hesitations, evident change of speed during performance of the key task and tested task, or mechanical trouble was discarded as being inconsistent.

Analysis of Data.--The product of the many experiments conducted to establish key task times was several pairs of time charts with recorded time postings. Of each pair, one chart consisting of key task times and the other consisting of accompanying tested task times were made. The mount upon which the posting mechanisms were fastened indexed horizontally following completion of each two phase (key task and tested task) performance. Accordingly, it was possible to identify specific pairs of key task times and accompanying tested task times comprising each performance.

For the purpose of fulfilling the first objective of the experiments, that is, the determination of the per cent increase of time, the tested task values were synthetically normalized and averaged. This was accomplished in the following manner:

(1a) A normal time was assumed for the one-hand twelve-inch push-pull key task. A value of 0.0140 minute was taken for this purpose. The validity of this assumption is explained later in this thesis.

(2) The actual key task time for each performance was divided into this assumed normal key task time to arrive at a factorial speed rating (based on the assumed normal time) at which the key task was performed.

(3) The factorial speed rating obtained in Step No. 2 was multiplied by the accompanying tested task time to give a normalized or leveled tested task time.

(4) The five normalized tested task time values for each experiment for each subject were averaged together.

(1b) The normal time was calculated for the two-hand twelve-inch push-pull key task. This was accomplished by applying the foregoing four-step procedure to the data from the experiments, described previously, consisting of one-hand twelve-inch push-pull key tasks and accompanying two-hand twelve-inch push-pull tested tasks. The resulting average normalized time values computed for each of the six tests (one test for each of six experimental subjects) were averaged together and this average value was used as the normal two-hand push-pull key task time.

(1c) The normal time for the twelve-inch one-hand lateral key task was calculated in a similar manner. The data from the experiments, described previously, consisting of twelve-inch one-hand push-pull key tasks and accompanying twelve-inch one-hand lateral tested tasks, were used for this calculation.

(1d) The normal time for the twelve-inch two-hand lateral key task was computed in a like manner, employing the experiments comprised of twelve-inch one-hand lateral key tasks and accompanying twelve-inch two-hand lateral tested tasks.

The average normalized time values for like experiments from each of the six tests were averaged together to establish a grand average normal time value for each type of experiment. The six individual means were each compared to their grand average by application of the Student's t test for significant differences of means. (27) A sample calculation showing application of this test is shown in Figure 7. Mean time values that differed significantly from the grand average, according to the t test, were discarded and a revised grand average was calculated. In no case were more than two averages discarded as a result of this test.

Each revised grand average normalized tested task time was divided by the assumed (or calculated) normal time for the corresponding key task. The resulting figure was multiplied by 100, and 100 was subtracted from the product. The per cents increase in time, calculated in this manner, for tasks of longer distance than twelve inches, based on the twelve-inch tasks, are shown on the graphs in Figures 1 and 2.

For the purpose of fulfilling the second objective of the experiments, that is, to determine significance of differences between the various types of motions, twenty <u>actual</u> (not normalized) tested task time values for each of the types of motions were averaged together. These twenty time values were portioned evenly among the experiments that had not been discarded because of non-consistency with their respective grand averages. The resulting mean values were compared with each other by further application of the Student's t test for determining significance of differences between two means. A sample calculation showing application of this test is shown in Figure 8. Actual time values were used for this analysis because the normalized time values were based on four different assumed normal key task times. It was also felt that since the experiments were all performed at a very fast speed, these actual time values would present an accurate estimate of the per cent differences in time needed to perform the various motions analyzed in this thesis.

CHAPTER VI

RESULTS

Experimental Procedure.--An experimental procedure has been designed for the purpose of research intended for the refinement of synthesis. This method is described in the preceding chapter as it was used in the research for this thesis. The results obtained from this procedure are explained in the following paragraphs.

Effect of Distance on Movement Time.--The next objective was to determine the percentage difference in the normal time of twelve-inch motions compared with longer motions. The procedure for accomplishing this objective has been described in the preceding chapter. The results obtained from this phase of the research are tabulated in Table 1. This table shows the average normalized time values for all of the experiments entailing a tested task longer than twelve inches. Table 1 also shows the grand averages of like experiments from each of the six tests.

The mean experiment time values that were significantly different (according to the Student t test described in the previous chapter) from the grand average of the six mean experiment time values at the five per cent probability level are noted in Table 1, by means of one asterisk. This means that this much difference may be expected to occur only one time in twenty due to chance variation. Thus, there are probably some assignable causes for this amount of inconsistency. The average experiment time value that was significantly different from the grand average at the one per cent probability level is noted by means of two asterisks. This indicates that this much variation may be expected to occur only one time in one hundred due to chance variation alone. In cases for which mean values were found significantly different from the grand average, the appropriate values were omitted, and a revised grand average was calculated as described in Chapter V. In no case were more than two values omitted as a result of this significance test. The revised grand averages are shown in the sixth column in Table 1.

The final grand average normalized tested task time value for each type of experiment was divided by two in order to calculate the value for the average normalized tested movement time. This was done because each task consisted of two identical movements. The resulting normalized movement times are shown in the last column of Table 1.

The final grand average normalized tested task time was divided by its appropriate normal key task time and multiplied by one hundred. Then one hundred was subtracted from same in order to determine the per cent increase in time needed to perform the tested task based on that needed to perform the key task. These percentages are shown in Table 2 and are graphed in Figures 1 and 2. Figure 9 compares, for like distances and like movement types, the per cent increase in time needed to perform the tested task as derived from this research with the percentage increase in time for Work Factor (a refined synthesis system) and Basic Motion Timestudy (a simplified synthesis system).

The mean normalized time values for three, six, and nine-inch tasks of each type of motion did not show sufficient variation from the normal time values for their respective twelve-inch key tasks. In some cases

Table 1. Average Normalized Tested Task and Tested Movement Times

Type of Motion Tested	Distance of Tested Motion in Inches	Subject	Mean Normalized Tested Task Time in Minutes	Grand Average Normalized Tested Task Time in Minutes	Revised Grand Average Tested Task Time in Minutes	Mean Normalized Tested Movement Time in Minutes
One Hand Push-Pull	18	A	.01612			
		B	.01800			
		C	.01617	0.01703		0.0085
		D	.01783			
		E	.01628			
		F	.01778			
	24	A	.01882			
		B	.02012*			
		C	.01942	.01929	.01927	.0096
		D	.01850*			
		E	.01966			
		F	.01919			
	30	A	.02196			
		B	.02215			
		C	.02117	.02289	.02201	.0110
		D	.02421*			
		E	.02510*			
		F	.02274			
Two Hand Push-Pull	18	A	.01902			
		B	.01766			
		C	.01723	.01845	.01803	.0090
		D	.01726			
		E	.01898			
		F	.02057*			

Table 1. Average Normalized Tested Task and Tested Movement Times (continued)

Type of Motion Tested	Distance of Tested Motion in Inches	Subject	Mean Normalized Tested Task Time in Minutes	Grand Average Normalized Tested Task Time in Minutes	Revised Grand Average Tested Task Time in Minutes	Mean Normalized Tested Movement Time in Minutes
Two Hand Push-Pull	24	A	.02278			
		B	.02003			
		C	.02161	.02261	.02141	.0107
		D	.02123			
		E	.02456*			
		F	.02545*			
	30	A	.02407			
		B	.02683			
		C	.02701	.02740	.02590	.0130
		D	.02568			
		E	.02978*			
		F	.03107*			
One Hand Lateral	18	A	.01816			
		B	.01888*			
		C	.01732	.01801	.01754	.0088
		D	.01731			
		E	.01904*			
		F	.01736			
	24	A	.02107			
		B	.02237			
		C	.01786*	.02083	.02069	.0104
		D	.02007			
		E	.02433*			
		F	.01925			

Table 1. Average Normalized Tested Task and Tested Movement Times (continued)

Type of Motion Tested	Distance of Tested Motion in Inches	Subject	Mean Normalized Tested Task Time in Minutes	Grand Average Normalized Tested Task Time in Minutes	Revised Grand Average Tested Task Time in Minutes	Mean Normalized Tested Movement Time in Minutes
One Hand Lateral	30	A	.02301			
		B	.02548			
		C	.01839**	.02385	.02436	.0122
		D	.02398			
		E	.02727*			
		F	.02498			
Two Hand Lateral	18	A	.01937			
		B	.01900			
		C	.01724	.01861	-	.0093
		D	.01815			
		E	.01984			
		F	.01803			
	24	A	.02222			
		B	.02384			
		C	.01788*	.02139	.02209	.0111
		D	.01931			
		E	.02468			
		F	.02039			

Table 1. Average Normalized Tested Task and Tested Movement Times (continued)

Type of Motion Tested	Distance of Tested Motion in Inches	Subject	Mean Normalized Tested Task Time in Minutes	Grand Average Normalized Tested Task Time in Minutes	Revised Grand Average Tested Task Time in Minutes	Mean Normalized Tested Movement Time in Minutes
Two Hand Lateral	30	A	.02392*			
		B	.02784			
		C	.02472	.02614	.02658	.0133
		D	.02708			
		E	.02820			
		F	.02507			

* Significantly different from the Grand Average at the 0.05 probability level.
** Significantly different from the Grand Average at the 0.01 probability level.

Table 2. Percentage Increase in Time Needed to Perform the Tested Tasks Over That Needed to Perform the Key Tasks

No. of Hands	Angle Between Motion and Edge of Table	Distance	Per Cent Increase Over Key Task Time
1	0°	18"	15.55
		24"	36.36
		30"	60.47
	90°	18"	21.71
		24"	37.71
		30"	57.29
2	0°	18"	14.51
		24"	45.59
		30"	75.10
	90°	18"	19.00
		24"	41.29
		30"	70.84

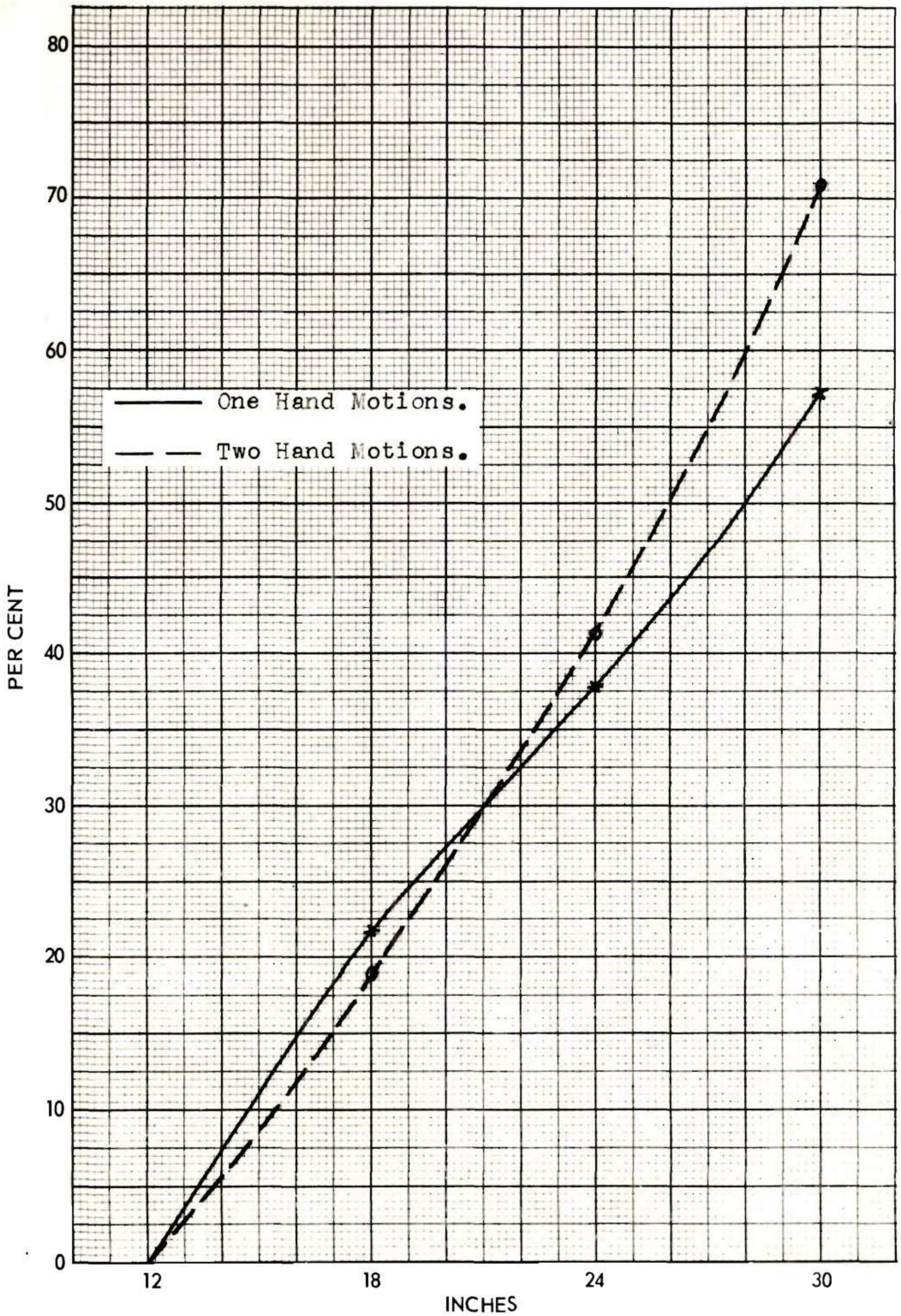

Figure 1. Per Cent Increase in Time Needed to Perform Longer Push-Pull Motions Based on the Time Needed for the Respective Twelve Inch Motions.

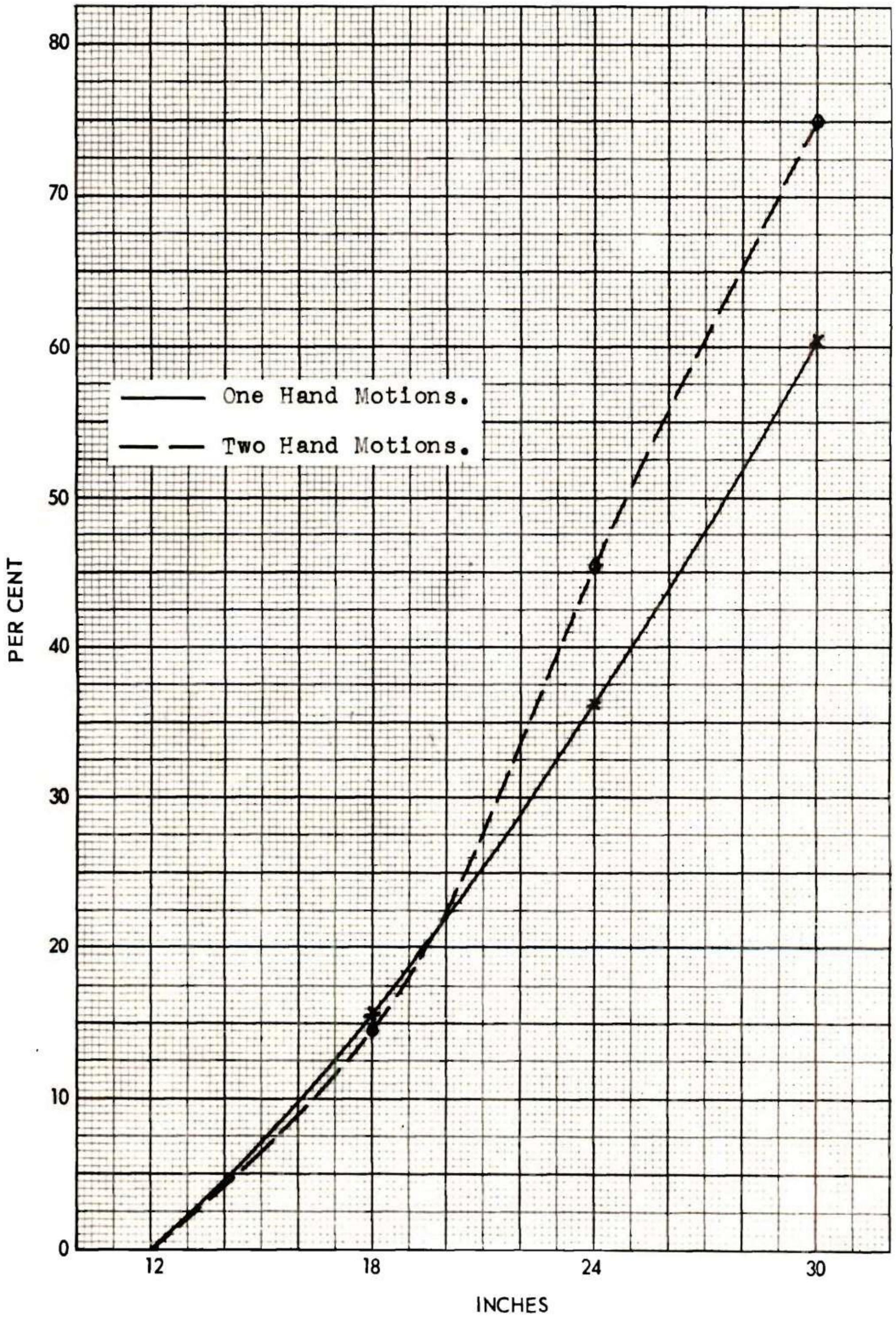

Figure 2. Per Cent Increase in Time Needed to Perform Longer Lateral Motions Based on the Time Needed for the Respective Twelve Inch Motions.

it took slightly longer to reach nine inches than to perform the twelve-inch reach. This result was noted for each of the subjects. It was felt that the reason for this was that the experiment subjects performed the key task first at a very fast pace and then inadvertently tried to perform the shorter distance task in the same length of time. This occurred in spite of the fact that the subjects were repeatedly cautioned against it. For this reason it was decided that the data for these short distances should not be used.

The average normalized time values for eighteen, twenty-four, and thirty-inch tested tasks seemed to follow a rational pattern. It was felt that the difficulty encountered with tested tasks of shorter distances was not encountered with those of distances longer than the twelve-inch key tasks, since the key tasks were performed first at a very fast pace and the subjects were not likely to have further increased this speed in performing the longer movement tasks.

Comparative Time Effects of Different Body Members.--The objective of this phase of the research was to measure the comparative time effects of different body members making movements of like distances. This phase of the research was intended to yield per cent slow down inherent in non-fundamental motions in comparison with fundamental motions (the one-hand lateral movement being here classed as the fundamental motion). As described in Chapter V, twenty representative actual tested task times for each type of experiment were used for this phase of the research. As previously mentioned, each experimental subject was instructed to exert constant maximum effort for all movement types tested. The mean actual time values and respective standard deviations for each type of experiment are tabulated in Table 3. Table 4 indicates the per cent increase in actual time taken to perform the various non-fundamental motions based on that taken to perform the one-hand lateral motion (the fundamental motion) for like distances. It was noticed that these percentage values for the thirty-inch tasks seemed erratic. It is probable that since this was an exceedingly long distance for the subjects to reach, varying amounts of awkwardness were experienced with these tasks. It is further felt that seated hand transports of this distance would seldom be warranted in industry. Therefore, it is felt the practical accuracy of the data would be increased by omitting these values from this phase of the research. The mean percentage values for the three distances (18 inches, 24 inches and 30 inches) and for the two distances (18 inches and 24 inches) are also shown in Table 4.

Because of this seeming awkwardness experienced in performing the thirty-inch tasks, the average actual time values for only the eighteen- and twenty-four-inch tasks were computed for the four types of motions. These average values, along with their respective standard deviations, are shown in Table 5. As explained in Chapter V, the Student t test for significance of differences between two means was applied to each of these four pairs of mean values.

The first hypothesis tested in this phase of the research showed that two-hand lateral motions are significantly slower than one-hand lateral motions at the five-per cent probability level when both motions are performed at maximum speed. There was an average increase in time of 6.51 per cent displayed in going from one to two hands for a lateral motion. Thus the test results indicate that this extent of increase in

Table 3. Average Actual Tested Task Times in Minutes

	One Hand		Two Hands	
Distance	Push-Pull	Lateral	Push-Pull	Lateral
18"	.00954 .00026	.00887 .00017	.00961 .00018	.00941 .00011
24"	.01167 .00038	.00995 .00026	.01144 .00028	.01064 .00020
30"	.01310 .00046	.01119 .00017	.01506 .00043	.01384 .00036

Table 4. Per Cent Increase in Time for the Various Motion Types Compared with Each Other

(a) Based on One-Hand Lateral Motions:

	One Hand		Two Hand	
Distance	Push-Pull	Lateral	Push-Pull	Lateral
18"	7.55	-	8.34	6.09
24"	17.29	-	14.97	6.93
30"	17.07	-	34.58	23.68
Mean (18"-30")	13.97	-	19.30	12.23
Mean (18"-24")	12.42	-	12.66	6.51

(b) Based on One-Hand Push-Pull Motions:

(c) Based on Two-Hand Lateral Motions:

	(b) Push-Pull		(c) Two Hand	
Distance	One Hand	Two Hand	Push-Pull	Lateral
18"	-	0.73	2.13	-
24"	-	-1.97	10.75	-
30"	-	14.96	8.82	-
Mean (18"-30")	-	4.57	7.23	-
Mean (18"-24")	-	-0.62	6.44	-

Table 5. Average Actual Time Values in Minutes for 18" and 24" Tasks and Results of Student's Tests for Significance of Differences Between these Time Values

	One Hand		Two Hand	
	Push-Pull	Lateral	Push-Pull	Lateral
	.0106	.0094	.0105	.0100
	.00198	.00135	.00145	.00100

	t	Probability Level*
One Hand, Push-Pull vs. Lateral	3.16	0.01
Two Hand, Push-Pull vs. Lateral	1.79	0.10
Push-Pull, One Hand vs. Two Hand	0.26	not sig.
Lateral, One Hand vs. Two Hand	2.25	0.05

* A probability level of 0.01 means that this much difference in time may be expected only one time in 100 due to chance variation if the two mean values actually represent the same population average.

time might be expected only once in twenty times if there were no actual increase in time but only variation in time due to chance causes.

The next hypothesis tested showed that there was no significant difference in time between the one- and two-hand push-pull motions. The small amount of variation present is very likely due to chance.

Testing of the next hypothesis showed that the one-hand push-pull motions are significantly slower than the one-hand lateral motions at the one-per cent probability level when both motions are performed at maximum speed. There was an average increase in time of 12.42 per cent displayed in going from one-hand lateral to a one-hand push-pull motion. Thus the test results indicate that this extent of increase in time might be expected only once in one hundred times if there were no actual increase in time but only variation in time due to chance causes.

The last hypothesis tested showed that the two-hand push-pull motions are significantly slower than two-hand lateral motions at the ten-per cent probability level. There was an average increase in time of 6.44 per cent displayed in going from a two-hand push-pull to a two-hand lateral motion. Thus the test results indicate that this extent of increase in time might be expected only once in ten times if there were no actual increase in time but only variation in time due to chance causes.

The results of this phase of the research are tabulated in Tables 4 and 5.

CHAPTER VII

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations to be discussed are based only on the experimental results, previously described in detail, entailing the following limitations:

(1) Hand transport motions were tested. These motions were:

(a) Performed from a seated position;

(b) Performed in the horizontal plane;

(c) Started and terminated with the hand(s) in a stationary position;

(d) Unimpeded;

(e) Non-skilled motions;

(f) Reach motions involving reaching directly in front of the body perpendicular to the edge of the table at which the operator was seated (push-pull motions), and directly to the side of the body parallel to the edge of the table at which the operator was seated (lateral motions);

(g) Performed at a very fast speed.

(2) The estimated per cent increase of normal movement time attendant to the increase of movement distance, based on twelve-inch movements, entailed the assumption that the tested tasks and accompanying key tasks were performed at like degrees of speed. This assumption is made for the following reasons:

(a) Rhythmic motion speed was possible throughout performance of the tested tasks and accompanying key tasks.

(b) The subjects were carefully instructed and repeatedly reminded to strive for consistent motion speed throughout each key task and tested task combination.

(c) The subjects moved at a rapid rate of speed, minimizing chances for difference of movement speed between key task performances and accompanying tested task performances.

(d) Inconsistencies not originally detected were later detected statistically.

(3) The estimated per cents increase of normal time required for performing the tested movement types, based on the one-hand lateral movement, were established by comparing actual tested task movement times (not normalized times) of different type for like distances. Thus, the stated per cents increase of normal time assumed:

(a) Each subject exerted the same degree of productive effort on all motion types, as instructed. (This is not meant to infer that the motion speed of all subjects was the same.) This assumption is made since each subject was instructed to exert maximum productive effort during all performances, noted deviations being discarded as previously described.

(b) The normal performance times for various simple movements of the type tested are directly proportional to the maximum speeds at which they can be satisfactorily performed.

(4) Only six subjects were tested. These six subjects were:

(a) Highly motivated because of the experimental nature of the work;

(b) Not a normal group in that they all scored within the upper forty percentile on the Moore Eye-Hand Coordination Test scale;

(c) Were all professional or college people, rather than factory workers for which a synthesis program should be intended;

(d) Assumed to be representative of all workers, since the tests were made on basic unskilled movements. Furthermore, all results are stated in terms of percentage differences in normalized times rather than absolute time values.

In view of the above limitations and the results of the experiments, the following conclusions and recommendations may be made:

(1) The first objective of this thesis, to develop an experimental procedure, has been accomplished. This method may be duplicated by others and was used for the research conducted in connection with this thesis. This procedure is recommended for all further researches intended for the refinement of synthesis.

(2) The second objective of this thesis was to determine the percentage difference in the normal time of twelve-inch motions compared with longer motions. These percentages may be determined from the curves in Figures 1 and 2. Normal times for the various key tasks should be determined by further research. When satisfactory normal times have been agreed upon, the percentage factors taken from Figures 1 and 2 may be used to arrive at normalized movement times for the various distances. To illustrate, the normal key task time for a twelve-inch one-hand push-pull movement was assumed to be 0.0070 minute. Based on this assumption, the per cent increase in normal time for performing the eighteen-inch one-hand push-pull movement was found to be 21.7 per cent, as previously explained. The slow-down factor corresponding to this per cent increase in time may be calculated by dividing this percentage (21.7) by one hundred and adding one. This factor would be 1.217 in this illustration. Now, assume the normal time for this key task (a basis for further research) is found to be 0.0060 minute. The normal time for the eighteen-inch movement may be determined by merely multiplying this new normal key task time by

the slow-down factor determined above. This would be equal to 0.0060 minute times 1.217 or 0.0073 minute.

This slow-down factor, based on an erroneous normal key task time, may be used in conjunction with a correct key task time. The validity of this statement may be illustrated as follows:

(a) The actual twelve-inch key task time accompanying the first eighteen-inch one-hand push-pull performance for subject A was 0.0082 minute.

(b) Dividing this time value into the assumed normal key task time of 0.0140 produced a factorial speed rating of 1.707.

(c) The actual eighteen-inch tested task time corresponding to the above-mentioned key task performance was 0.0094 minute.

(d) Multiplying this tested task time by its factorial speed rating determined in step (b) results in a normalized tested task time of 0.01605 minute. This is a 14.6 per cent increase in time over the assumed normal key task time of 0.0140 minute.

(e) If the normal key task time were actually 0.0120 minute rather than 0.0140 minute the factorial speed rating for this two-phase performance should be 1.463.

(f) Multiplying the tested task time of 0.0094 minute by this new speed rating factor results in a normalized tested task time of 0.01375 minute.

(g) This normalized tested task time is also a 14.6 per cent increase in time over that of the normal key task upon which it was based (0.0120 minute). Therefore, the per cents increase in normal tested task time based on an erroneous key task time may be used directly in conjunction with a correct key task time.

The movements shorter than twelve inches should be investigated again, using a motion pattern similar to that used in this research. However, it is recommended that the tested task be performed first, followed by the key task. This would preclude the tendency to slow down that was so prevalent during this research.

It is further recommended that studies be made to determine if the percentage increases in normal times for movements greater than twelve-inch distances, based on the twelve-inch movements, established in this research, are significantly different statistically from those represented in various synthesis systems presently in use.

(3) The final objective of this investigation was to measure the comparative time effects of different body members making movements of like distances. The results of this phase of the research indicate the following to be true, based on an assumption that normal movement times should be proportionate to the minimum movement times considered in this investigation:

(a) Approximately six per cent more time is needed to perform the two-hand lateral movements than was needed to perform the one-hand lateral movements investigated in this research, when the operator is exerting normal productive effort.

(b) There was no statistically significant difference in normal times for performing the one-hand push-pull movements and the two-hand push-pull movements.

(c) Approximately twelve per cent more normal time is required to perform the one-hand push-pull movements than is required to perform the one-hand lateral movements.

(d) Approximately six per cent more normal time is required to perform the two-hand push-pull movements than is required to perform the two-hand lateral movements.

(e) Approximately twelve per cent more normal time is required to perform the two-hand push-pull movements than is required to perform the one-hand lateral movements.

It is apparent from these results that the increased time factors to be applied to the various motion impedances are not additive. In other words, the increase of normal time entailed in changing from an unimpeded movement of a given distance to a movement entailing two or more impedances is not equal to the unimpeded movement time plus the time effects of the impedances entailed in going from unimpeded to single impedance movements. This conclusion is based on the following data:

(a) The two-hand lateral movements were approximately six per cent slower than the one-hand lateral movements.

(b) The one-hand push-pull movements were approximately twelve per cent slower than the one-hand lateral movements.

(c) The two-hand push-pull movements, which entail both of the above-mentioned motion impedances having a total of eighteen per cent slow down based on the one-hand lateral movements, were but twelve per cent slower than the one-hand lateral movements.

General Recommendations.--The various slow-down factors determined above were based on the average of the eighteen- and twenty-four-inch performance times for each type of motion. However, the results of this research indicate that the actual slow-down factors for each of these distances are different. In view of this, it is recommended that these factors be investigated for other distances to determine the various factors that should be used. Furthermore, if it is shown that these slow-down factors vary with distance, more distances (probably at three-inch intervals) should be measured in order to determine factors that may be used in the development of a refined synthesis system.

This study was intended as the first step in the development of a refined synthesis program. The refined program should entail similar investigations of other transport movements and grasp and positioning movements. The experimental procedure used in this research is recommended for use in the investigations needed for the program. It is felt that the results established (and the experience gained through difficulties encountered) in this research provide a sound basis for the total refined program.

APPENDIX

Table 6. Results of the Accuracy Test of the Auto-Graphic Time Study Machine

	Chart No. 1			Chart No. 2		
Cycle No.	Clock Time (Minute)	Posted Time (Minute)	Error	Clock Time (Minute)	Posted Time (Minute)	Error
1	0.00900	0.00890	-0.00010	0.00850	0.00830	-0.00020
2	0.00800	0.00820	+0.00020	0.00850	0.00820	-0.00030
3	0.00867	0.00880	+0.00013	0.00867	0.00870	+0.00003
4	0.00834	0.00820	-0.00014	0.00850	0.00850	-
5	0.00950	0.00930	-0.00020	0.00867	0.00900	+0.00033
6	0.00934	0.00930	-0.00004	0.00867	0.00860	-0.00007
7	0.00900	0.00890	-0.00010	0.00817	0.00760	-0.00057
8	0.00850	0.00850	-	0.00850	0.00840	-0.00010
9	0.00834	0.00820	-0.00014	0.00834	0.00830	-0.00004
10	0.00917	0.00910	-0.00007	0.00817	0.00770	-0.00047
11	0.00934	0.00950	+0.00016	0.00783	0.00790	+0.00007
12	0.00917	0.00930	+0.00013	0.00750	0.00690	-0.00060
13	0.00950	0.00960	+0.00010	0.00867	0.00840	-0.00027
14	0.00867	0.00870	+0.00003	0.00783	0.00740	-0.00043
15	0.00850	0.00880	+0.00030	0.00834	0.00840	+0.00006
16	0.00900	0.00900	-	0.00817	0.00750	-0.00067
17	0.00884	0.00860	-0.00024	0.00783	0.00780	-0.00003
18	0.00884	0.00840	-0.00044	0.00834	0.00770	-0.00064
19	0.00867	0.00860	-0.00007	0.00817	0.00770	-0.00047
20	0.00950	0.00960	+0.00010	0.00850	0.00800	-0.00050
21	0.00884	0.00890	+0.00006	0.00800	0.00790	-0.00010
22	0.00884	0.00860	-0.00024	0.00834	0.00820	-0.00014
23	0.00917	0.00900	-0.00017	0.00834	0.00800	-0.00034
24	0.00867	0.00870	+0.00003	0.00834	0.00820	-0.00014
25	0.00900	0.00910	+0.00010	0.00834	0.00790	-0.00044
	Algebraic Totals		-0.00061			-0.00603
	Average Errors		-0.00002			-0.00024

Table 7. Experimental Subjects

Subject	Sex	Age at Nearest Birthday	Occupation	Moore Eye-Hand Coordination Test Score Percentile	Arm Length in Inches	Date of Experiment
A	Female	27	Registered Nurse	85	27.50	July 6, 1954
B	Female	28	Registered Nurse	60	26.00	July 13, 1954
C	Female	22	Elementary School Teacher	90	26.50	July 19, 1954
D	Male	28	College Senior	95	30.50	July 11, 1954
E	Male	28	Graduate Student	80	27.75	July 8, 1954
F	Male	30	Graduate Student	60	28.85	July 15, 1954

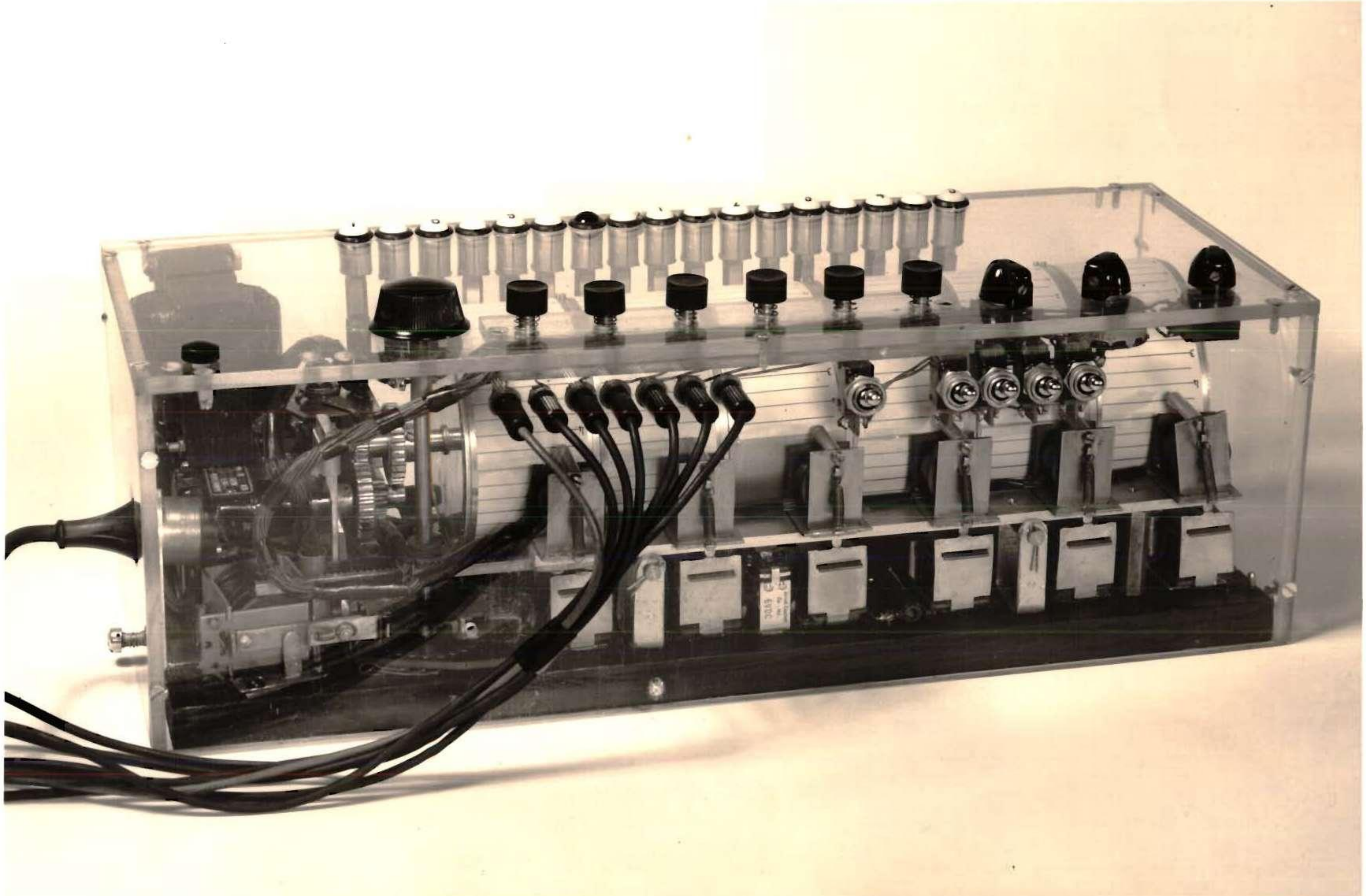

Figure 3. Auto-Graphic Time Study Machine

$$\sigma_1 = \sqrt{\frac{\sum_{i=1}^{n} X_i^2}{n - 1} - \frac{\left(\sum_{i=1}^{n} X_i\right)^2}{n(n - 1)}} = \sqrt{\frac{.0000006731}{24} - \frac{(.00329)^2}{600}} = 0.00010 \text{ minute}$$

$$\sigma_2 = \sqrt{\frac{.0000031171}{24} - \frac{(.00701)^2}{600}} = 0.00022 \text{ minute}$$

$$\sigma_{\overline{X}_1} = \frac{0.00010}{\sqrt{25}} = 0.00002 \text{ minute}$$

$$\sigma_{\overline{X}_2} = \frac{0.00022}{\sqrt{25}} = 0.00004 \text{ minute}$$

Figure 4. Calculation of Standard Deviation of Errors for Accuracy Test of the Auto-Graphic Time Study Machine

Figure 5. Work Place Layout

Figure 6. Sample Time Chart Used with the Auto-Graphic Time Study Machine to Record Time Intervals

18 Inch, One Hand, Push-Pull, Operator B

$$t = \frac{\bar{X} - \bar{X}^1}{\sigma/\sqrt{n}} = \frac{0.01800 - 0.01703}{0.00092/\sqrt{6}} = 2.55$$

Where $\bar{X}$ = Average Normalized Tested Task Time for Operator B

$\bar{X}^1$ = Grand Average Normalized Tested Task Time

σ = Standard Deviation of the Averages

n = Number of Averages

From Tables for Values of t:

At $n - 1 = 5$ Degrees of Freedom $t_{.05} = 2.57$

Therefore These Two Values are not Significantly Different at the 0.05 Probability Level.

Figure 7. Sample Calculation of Student's t test for Significance of Difference Between a Single Mean and a Grand Average

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma_p} \sqrt{\frac{n_1 \times n_2}{n_1 + n_2}}$$

Where $\sigma_p^2 = \dfrac{(n_1 - 1)\sigma_1^2 + (n_2 - 1)\sigma_2^2}{n_1 + n_2 - 2}$

Since $n_1 = n_2$, These Equations Resolve Themselves to:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma_p} \sqrt{\frac{n}{2}}$$

$$\sigma_p^2 = \frac{\sigma_1^2 + \sigma_2^2}{2}$$

Sample Calculation for: $\bar{X}_1$ = Average Actual One-Hand Push-Pull Tested Task Time

$\bar{X}_2$ = Average Actual One-Hand Lateral Tested Task Time

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sigma_p} \sqrt{\frac{n}{2}} = \frac{.0106 - .0094}{.00170} \sqrt{\frac{40}{2}} = 3.16$$

$$\sigma_p = \sqrt{\frac{\sigma_1^2 + \sigma_2^2}{2}} = \sqrt{\frac{(.00198)^2 + (.00135)^2}{2}} = .00170 \text{ Minute}$$

From Tables for Values of t: at $2n - n = 78$ Degrees of Freedom, $t_{.01} = 2.65$

Therefore $\bar{X}_1$ is Significantly Greater than $\bar{X}_2$ at the .01 Probability Level

Figure 8. Sample Calculations for Tests of Significance of Differences Between Two Means

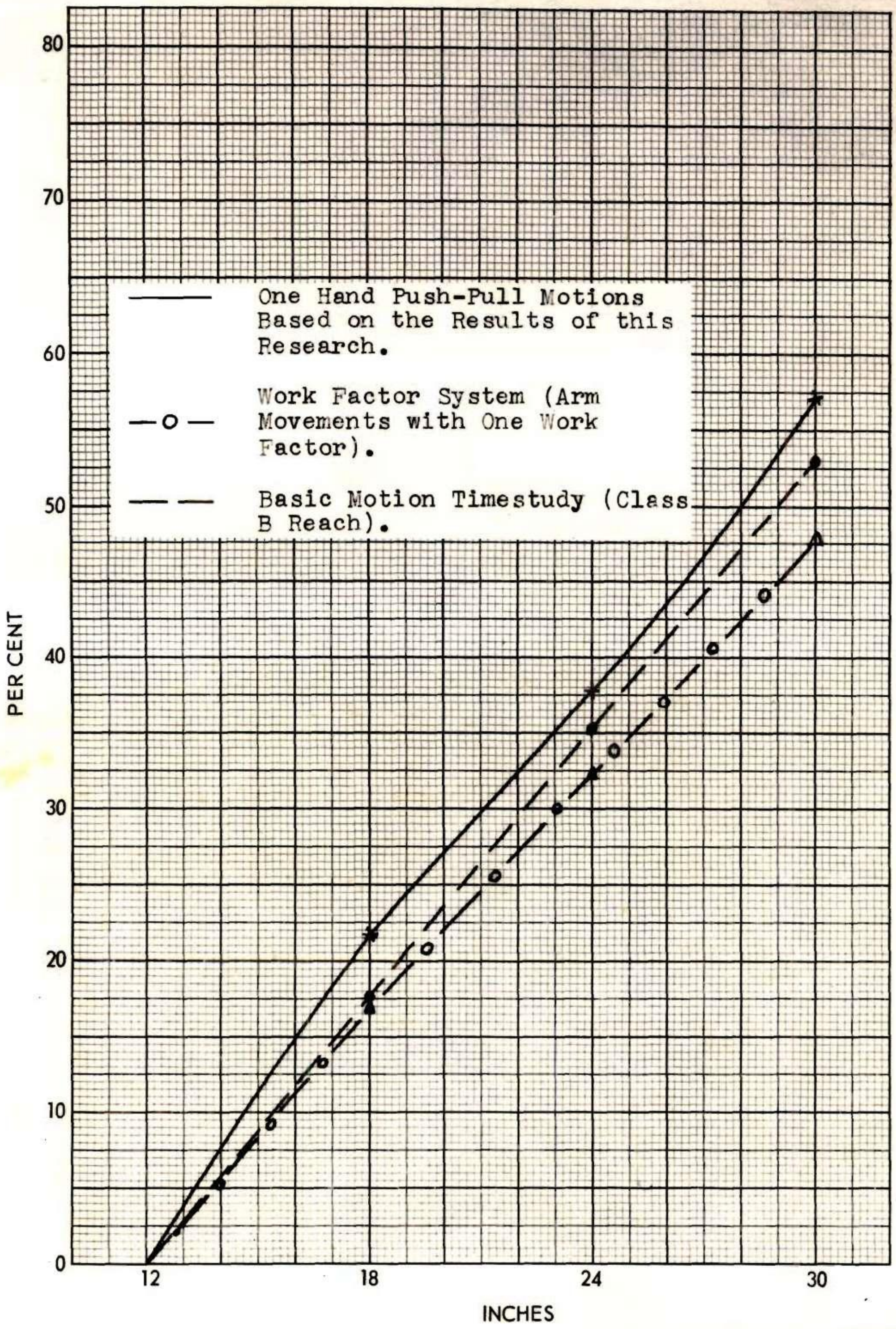

Figure 9. Per Cent Increase in Time Needed to Perform Longer One Hand Push-Pull Motions Based on the Time Needed to Perform the Twelve Inch Motion Compared with Similar Calculations from the Work Factor and Basic Motion Timestudy Systems.

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